PB81-148736

Small Water Systems: Role of Technology

(U.S.) Municipal Environmental Research Lab.
Cincinnati, OH

26 Mar 79

U.S. Department of Commerce
National Technical Information Service
NTIS.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/J-80-207	2. JOURNAL ARTICLE
3. RECIPIENT'S ACCESSION NO. PB81 148236	
4. TITLE AND SUBTITLE: Small Water Systems: Role of Technology	5. REPORT DATE: February 1980
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S): Robert M. Clark	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Drinking Water Research Division, Municipal Env. Research Laboratory, USEPA, 26 West St. Clair St., Cinti, Ohio 45268	10. PROGRAM ELEMENT NO. PE No. BIVC1A
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS: Same as above.	13. TYPE OF REPORT AND PERIOD COVERED
	14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Contact: Robert M. Clark (513) 684-7488

16. ABSTRACT

Over 90% of the nation's water supplies serve fewer than 10,000 people, less than 25% of the total population. Many of these small systems have problems. One of the major problems is their lack of operating revenues. They cannot benefit from economies of scale as do large urban systems because they are small in terms of the number of connections served. Recent epidemiological evidence has shown that the majority of the recent waterborne disease outbreaks occurred in small systems. There are, however, technological and management systems being developed that may aid small utilities in solving their problems at reasonable cost. These technological systems include package treatment plants and reverse osmosis plants. Management systems include cost accounting systems.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT: Release to public.	19. SECURITY CLASS (This Report): Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS (This page): Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

PB81-148736

EPA-600/J-80-207
JOURNAL ARTICLE

15181 FEBRUARY 1980 EE1

ASCE, Vol. 106, No.EE1
pages 19-35, 1980.

JOURNAL OF
THE ENVIRONMENTAL
ENGINEERING DIVISION

SMALL WATER SYSTEMS: ROLE OF TECHNOLOGY

By Robert M. Clark,[1] M. ASCE

INTRODUCTION

Approx 177,000,000 people are served by community water supplies in the United States. Over 90% of the nation's water supplies serve fewer than 10,000 people, less than 25 percent of the total population. Table 1 shows the relationship between system size and population served.

In addition to the large number of small community water supplies there are approx 200,000 public noncommunity water systems. Most of these systems are privately owned and found at service stations, motels, restaurants, etc. Data on these systems are limited.

Small water systems in general have many problems. One major problem is their lack of operating revenues. They cannot benefit from economies of scale as do large urban systems because they are small in terms of the number of connections served. Certain types of services must be provided, no matter how few the number of connections, causing the unit costs to rise as the number of connections being serviced decreases. The initial construction cost of the treatment and distribution system may also be high relative to the number of connections.

An offsetting factor is that small systems may be relatively easier to operate because they are somewhat less complicated than larger systems. Nevertheless, the price paid for service is likely to be higher, sometimes much higher, than residents of urban areas pay.

Another major problem associated with small water supplies is that of providing high quality drinking water. Epidemiological evidence has shown that the majority of recent waterborne disease outbreaks occurred in small systems. These outbreaks are primarily due to the inadequacy of treatment technology, which is of course related to inadequate revenues.

Note.—Discussion open until July 1, 1980. To extend the closing date one month, a written request must be filed with the Manager of Technical and Professional Publications, ASCE. This paper is part of the copyrighted Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 106, No. EE1, February, 1980. Manuscript was submitted for review for possible publication on March 26, 1979.

[1]Engrg. Systems Analyst, Drinking Water Research Div., Municipal Environmental Research Lab., U.S. Environmental Protection Agency, Cincinnati, Ohio.

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

Other problems include inadequate operator training and a lack of knowledge concerning proper management procedures. These problems could also be solved with the availability of proper training programs and through technology transfer.

Newly proposed standards in the Safe Drinking Water Act (SDWA) will compound these problems. Systems forced to install new technology in order to meet these standards will in some case experience significant cost increases.

This paper explores some of the factors influencing the cost of water in small systems (economies of scale). Some of the evidence accumulated to support the contention of drinking water quality problems in small systems are examined along with examples of the costs associated with alternative technologies available to meet water quality problems in small systems. The regionalization concept, often presented as a panacea for small systems, is also explored. Finally, research efforts being conducted to provide technology and management techniques that may assist small systems managers are considered.

TABLE 1.—Distribution of Community Water Systems (5)

Systems size, in persons served (1)	Number of water systems (2)	Percentage of total systems (3)	Total population served, in thousands (4)	Percentage of total population served (5)
25 to 99	7,008	18	420	0.2
100 to 9,999	30,150	75	36,816	20.8
10,000 to 99,999	2,599	6	61,423	34.6
100,000 and over	243	1	78,800	44.4
Total	40,000	100.1	177,459	100.1

It is hoped that the information presented in this paper will clarify some of the issues related to small systems problems and help suggest some feasible solutions.

Economies of Scale

Small systems in many ways are the victims of their size. A prevailing characteristic of water supply technology is the effect of economies of scale (increasing unit costs with decreasing system size). In an early study revealing this phenomenon, Orlob and Lindorf examined treatment cost to determine its relationship to the cost of surface water transportation, reclamation of wastewaters, ground-water recharge, and any other alternatives available for increasing water supply in California (11). Construction cost was theorized as a function of the explanatory variable, design capacity, as follows:

$$C_c = \alpha Q_n^{\beta} \quad \ldots\ldots\ldots\

$$C_c = 257\, Q_n^{0.67} \quad \ldots\ldots\ldots\

Table 2 contains values for the right-hand side of Eq. 4 at selected points.

As can be seen from Table 2 and Fig. 1, significant differences exist in the slopes of various curve segments. One possible definition for a "small" system is one with a high unit cost or, equivalently, one with a capacity that puts it within the segment of the cost curve (Fig. 1) having the maximum slope. Such a system would have a capacity of 2.5 mgd (9,500 m^3) or less. Following this convention a system having approx 2.5 mgd (9,500 m^3) but less than 20 mgd (7,600 m^3) is transitional and those systems of 20 mgd (76,000 m^3) or greater are large.

TABLE 3.—Costs for Large and Small Water Supplies by Function (1974), in cents per 1,000 gal

Utility size (1)	Revenue producing water, in millions of gallons per day (2)	Support services (3)	Acquisition (4)	Treatment (5)	Distribution (6)	Interest (7)	Total (8)
Large	86[a]	9.9	5.4	4.8	12.7	8.7	41.5
Small	1.7[b]	15.0	12.4	8.8	35.3	12.9	85.4

[a]Average of 12 systems.
[b]Average of 23 systems.
Note: 1 gal = 3.8×10^{-3} m^3; 1¢/1,000 gal = 0.26¢/m^3.

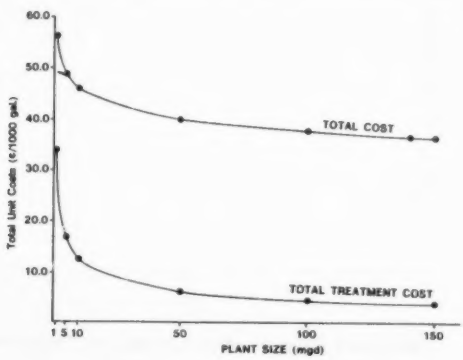

FIG. 2.—Total Unit Costs for Water Supply Systems and Treatment

Recent studies confirm these effects. Fig. 2 shows the results from a detailed study of expenditure patterns over 10 yr for 12 water utilities geographically scattered across the United States (2). Both total supply cost and total treatment cost are shown.

Table 3 summarizes data collected on both large and small systems (1974 costs) (1). As can be seen, the average cost of 12 large water supplies averaging approx 85 mgd (323,000 m^3) is 42¢/1,000 gal (10.9¢/m^3). The average cost for 30 small supplies averaging approx 1.7 mgd (6,460 m^3) is 85¢/1,000 gal

(22.1¢/m^3). Unit costs for the small systems are uniformly higher in all of the cost categories.

Table 3 and Eq. 3 illustrate the impact that the new regulations may have on small systems. Table 3 shows the high unit costs currently associated with small systems. Installation, operation, and maintenance of sophisticated control processes together with monitoring requirements may result in substantial total and unit cost increases for small systems, as shown by Eqs. 1 and 3. The combination of high existing unit costs coupled with the possibility of even higher costs that may result from installation of new technology are justification enough for concern over the small systems problems.

Water Quality Problems

Not only do small systems have cost problems, but they also seem to have drinking water quality problems. Classical waterborne diseases of the past

TABLE 4.—Summary of Water Quality Evaluation (3)

(1)	Less than 500 (2)	500–100,000 (3)	Greater than 100,000 (4)	All populations (5)
(*a*) Population Group Served				
Number of systems	446	501	22	969
Study population in each group, in thousands	88	4,652	13,463	18,203
(*b*) Percentage of Systems				
Evaluation of systems				
Met drinking water standards	50	67	73	59
Exceeded recommended limits	26	23	27	25
Exceeded mandatory limits	24	11	0	16

years—typhoid fever, amoebic dysentery, and bacillary dysentery—were brought under control by the use of sand filtration, chlorination disinfection, and the application of drinking water standards. Recent epidemiological evidence by Craun and McCabe shows that the number of all waterborne disease outbreaks dropped from 45/100,000 people in 1938–1940 to 15/100,000 people in 1966–1970 (4). The average annual number of outbreaks ceased to fall around 1951 and may have increased slightly since then for reasons unknown at this time (8). Many of these outbreaks of communicable disease have occurred in small systems.

Table 4 summerizes the findings of the 1969 Community Water Supply, which included 969 water supply systems serving about 18,200,000 people. The study used the 1962 Public Health Service Drinking Water Standards as the basis for evaluating the performance of the systems. Table 4 shows that 41% of the systems exceeded either recommended or mandatory limits (3).

Deficiencies included the following: (1) Inadequate source protection; (2) improper disinfection or control of disinfection, or both; (3) inadequate clarifica-

tion (removal of suspended matter) or control of clarification, or both; and (4) insufficient pressure in the distribution system.

Costs for Meeting Drinking Water Standards

An obvious solution for providing high quality drinking water would be to install appropriate technology to assure that the finished drinking water will meet the standards. The addition of new technology may substantially raise the cost of the product to the consumer.

All of the information presented points toward potentially severe economic impacts on those small systems forced to make large investments to meet the standards. In order to provide some concrete information concerning adverse

TABLE 5.—Cost Estimates for Nitrate Removal by Ion Exchange

Item (1)	Quantity (2)
Flow treated, in millions of gallons per day	0.11
Capital cost, in dollars	
Construction cost	74,909
Site work	3,745
Engineering	8,809
Land	0
Legal, fiscal, administration	3,823
Interim during construction	1,131
Total (4)	101,858
Amortized capital—7%, 20 yr, in dollars per year	9,615
Operating and maintenance cost, in dollars per year	
Building and process energy at 3¢/kW-hr	465
Maintenance material	2,798
Labor at 10$/hr	11,010
Chemicals[a]	6,801
Total annual operating and maintenance cost, in dollars per year	21,774
Total annual cost, as a percentage per year	30,689

[a]Regenerant at $28.00/ton.
Note: 1 gal = 3.80×10^{-3} m^3.

impacts, a study of 23 selected small water supply systems in Environmental Protection Agency (EPA) Regions III, V, and VI was conducted.

Cost-Quality Evaluation.—Cost data and raw and finished water quality samples were taken at each of the small utilities visited in the survey. A complete inorganic chemical profile was developed and a comparative analysis of treatment removal efficiencies was made for each system. In some cases the existing treatment plant was failing to adequately remove constituents from the raw water causing the utility to fail to meet the Safe Drinking Water Act Maximum Contaminant Levels (MCL) (9). After examining the complete spectrum of chemical determinations for the raw and finished samples from each utility a decision was made as to whether or not a new treatment technology could be added so that finished water quality would meet existing MCL. Cost estimates

were made for the proposed technology at each affected utility. For example, in Region III, one utility was identified as having a nitrate removal problem. After examining data from the raw and finished samples a hypothetical ion exchange system was assumed. Table 5 summarizes the cost calculations for an ion exchange unit to solve the utilities nitrate removal problems.

In a similar manner, cost estimates were developed for add-on technologies in the other utilities identified as having problems (6). Table 6 shows utility designation, the region, the quality problem for each impacted utility, and the types of treatment hypothesized for solution. Six utilities in all were identified as having water quality problems. Table 7 contains the cost estimates for each alternative.

This cost impact analysis is hypothetical, and as can be seen from Table 7, more than one type of treatment may be applied to solve the same problem. But, depending on size, the costs associated with each technology can be very different. To properly select a treatment system for any utility requires more extensive design considerations than is possible here, and should include pilot testing. This analysis does provide, however, some realistic estimates of the

TABLE 6.—Utilities Selected for Cost Impact Analysis

Region (1)	Utility (2)	Quality problems (3)	Hypothesized treatment (4)
III	1	Nitrate	Ion exchange
V	1	Manganese	Chemical oxidation; ozone
	2	Barium	Zeolite; lime softening
	3	Barium	Zeolite; lime softening
	4	Barium	Zeolite; lime softening
VI	1	Total dissolved solids and fluorides	Activated alumina; reverse osmosis

potential costs that a small system might incur in attempting to meet the Safe Drinking Water Act requirements. Although current interest has centered on the costs associated with applying treatment technology for the removal of trihalomethanes and synthetic organics, the cost of meeting the existing interim standards in some small utilities may be high.

The solid line in Fig. 3 shows the current average unit costs for all of the utilities studied over the 10-yr time span. The average unit cost for meeting the standards for all of the utilities is shown by a dotted line in year 10. For the entire sample, the cost is increased by less than 5% but, as shown by Table 7, cost increases for some utilities may be significant.

Regionalization Concept

A commonly suggested panacea for small systems problems is that of regionalization in which a small community can join with other small communities or with a larger community to form a regional water supply. Two approaches can be considered when attempting to develop a regional compact or system.

TABLE 7.—Estimated Economic

Item	Utility III-1	Utility V-1		Utility V-2	
(1)	(2)	(3)	(4)	(5)	(6)
Water treated, in millions of gallons per day	0.13	1.17	—	0.41	—
Revenue-producing water, in millions of gallons per day	0.11	0.67	—	0.27	—
Proposed treatment technique	Ion exchange (nitrate removal)	Chemical oxidation	Ozonation	Ion-exchange softening	Lime softening
Construction cost for proposed treatment, in dollars	101,858	5,913	71,744	137,000	622,152
Amortized capital cost for proposed treatment (7% ≥ 20 yr), in dollars	9,615	559	6,773	12,934	58,727
Annual operations and maintenance cost for proposed treatment, in dollars	21,074	2,528	7,136	28,547	80,628
Total annual cost for proposed treatment, in dollars	30,689	3,087	13,909	41,481	139,355
Current annual total cost for water supply, in dollars	16,559	299,387	299,387	69,328	69,328
Projected annual total cost for water supply (with proposed treatment), in dollars	47,248	302,474	313,296	110,809	208,683
Current unit cost for water supply, in cents per 1,000 gallons	41.2	122.4	121.2	70.3	70.3
Projected new unit cost for water supply (with proposed treatment, in cents per 1,000 gallons)	117.7	123.7	128.1	112.4	211.8

Note: 1 gal = 3.8×10^{-3} m^3; 1¢/1,000 gal = 0.26¢/m^3.

Impacts for Small Systems

Utility V-3		Utility V-4		Utility VI-1	
(7)	(8)	(9)	(10)	(11)	(12)
0.45	—	0.066	—	1.08	—
0.34 Ion-exchange softening	— Lime softening	0.055 Ion-exchange softening	— Lime softening	0.78 Activated alumina	— Reverse osmosis
141,512	643,792	86,518	368,816	180,722	1,129,902
13,358	60,769	8,167	34,814	17,057	106,655
30,094	83,462	12,612	49,170	24,937	204,412
43,452	144,231	20,779	83,984	41,994	311,065
46,470	46,470	13,078	13,078	231,006	231,006
89,922	190,701	33,857	97,062	273,000	542,073
37.4	37.4	65.1	65.1	81.1	81.1
72.5	153.7	168.7	483.5	95.9	190.4

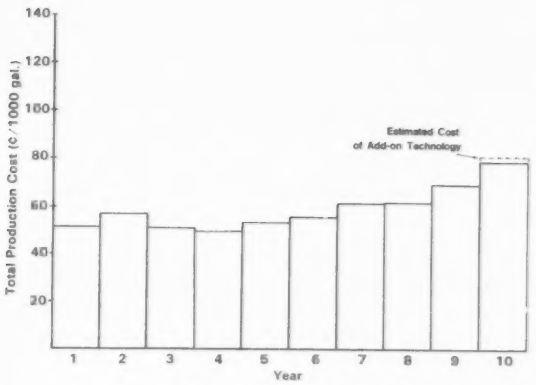

FIG. 3.—Average Production Cost for All Utilities with Estimated Cost of Add-On Technology

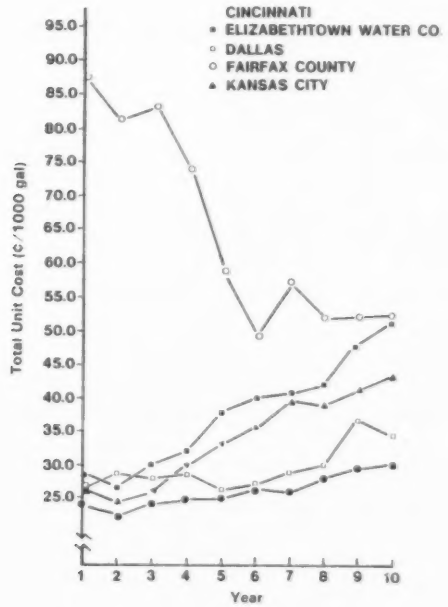

FIG. 4.—Total Unit Cost for Utilities

One approach involves the centralization of purchasing, maintenance, and various management support items. Another approach involves physically interconnecting existing systems.

The Safe Drinking Water Act, along with other environmental legislation, encourages the development of regional systems for managing water supplies. Regionalization has great appeal to regulatory groups because it reduces the number of individual entities with which they must work. Table 4 demonstrates

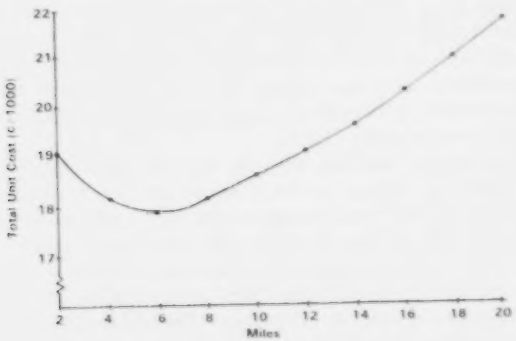

FIG. 5.—Cost of Water Versus Distance Transported

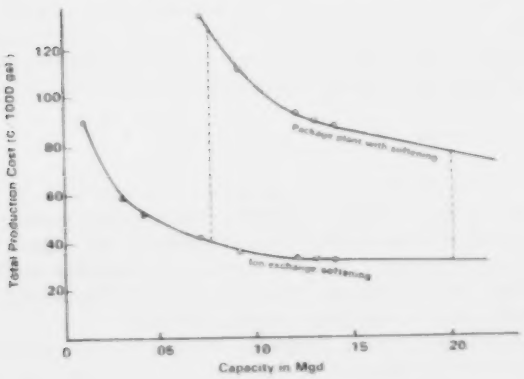

FIG. 6.—Comparative Costs of Package Plant and Ion Exchange Softening Systems

that small systems tend to have more quality control problems than do large systems. A common argument is that regional systems hydraulically interconnected exhibit economies of scale, thereby minimizing costs to the consumer. The following section examines some of these issues.

Hydraulically Interconnected Systems.—The economies of scale argument holds for a limited set of circumstances, as can be demonstrated by the following data. Fig. 4 shows unit costs of water treatment uncorrected for inflation for

the Fairfax County Water Authority (Virginia) and for four other utilities over a 10-yr period.

The Fairfax County Water Authority was developed by acquiring individual water service areas around the original Alexandria Water Company and, as such, has become a regional water supply utility. These data support an economies of scale argument. Compared to the other nonregional utilities, the unit costs for the Fairfax Authority continuously declined between years 1 and 5, the periods of maximum growth.

On the other hand, research indicates that limitations to the economies of scale associated with regionalization may exist. In order to study the effect of regional solutions, a computer simulation model for a minicipal water utility has been developed. The cost output from the model may be employed to analyze the cost trade-off between the central plant and decentralized transmission components of a water utility (2,11).

Fig. 5, which results from this analysis, shows how the unit cost varies over the service area with respect to the distance the water must be transmitted. As can be seen, the unit cost decreases until the 7-mile point, and then rises rapidly along this line as both quantity distributed and distance to the service area change. Fig. 5 clearly shows that there are limitations to the least-cost size of a water utility service area. This demonstrates that a minimum unit cost of supply exists in relation to distance. The implication for regional water supply is that economies of market area gained by a centralized plant dissipate in the transmission/distribution system at approx 7 miles–8 miles from the plant. After that point, unit costs continue to rise. Therefore, regionalization of water utilities may not be a priori justified by the economies of scale argument. It depends upon how close the respective utilities are, as well as the difference between marginal costs of all-on treatment technologies and the additional costs of the transmission/distribution system expanded to link the utilities.

Technological Solutions

Much effort has been and will continue to be expended in attempting to find solutions for small systems problems. As described earlier, many of the problems associated with small systems compliance are related to the proper use of existing technology. EPA is, therefore, conducting research into the various treatment techniques that might be appropriately applied to the broad range of small system contaminant removal problems.

EPA Small Systems Research Program.—Monitoring requirements outlined in the SDWA are leading many small water utilities to sample their water sources for inorganic contaminants for the first time. These monitoring data will no doubt reveal many new problems, particularly for small communities. Upon discovering that their supplies do not meet the regulations, many small communities will very likely first seek an alternative source of supply. If an alternative source is not available, treatment of an existing supply may be considered.

In recognition of this problem, the EPA Drinking Water Research Division has been conducting research into removal of inorganic substances, the contaminants most likely to be a problem to these communities. Most of this research has been directed toward the removal of eight heavy metals.

The research program is evaluating the effectiveness of conventional coagula-

tion and lime softening processes for removal of these metals. If they are found to be ineffective, then ion exchange and reverse osmosis are examined. Research is conducted in two phases: (1) A series of laboratory jar tests to determine the critical variables, such as pH, coagulant type and dose, and contaminant concentration, affecting the removal of contaminants from water; and (2) pilot plant tests to verify laboratory results. Results from these studies have been presented in a series of papers (12,13). Other research being conducted relates to the removal of organics and radioactive substances in small systems.

Point-of-Use Technology.—Point-of-use alternatives can be used to provide treatment to either one or a small number of homes. For single contaminant removal, a frequent problem in very small systems, they may be economically feasible. Fig. 6 shows comparative costs for a package plant softening system and an ion-exchange softening system (6). As can be seen by the dotted lines at 0.075 mgd (285.0 m^3/day) and 0.20 mgd (760 m^3/day) the single purpose ion-exchange softening system is considerably cheaper at small flows than is the package plant softening system. But as capacity increases, Fig. 6 shows that the curves come together and will eventually cross. This analysis points to the possibility that special purpose quasi point-of-use treatment (serving a few dwellings) might be more economical at low capacity requirements than more conventional units. A research program is being conducted into the microbiological characteristics of point-of-use systems for individual home use. Preliminary analysis indicates that these household systems may not meet quality standards.

Package Plant Technology.—Package water treatment plants, consisting of prefabricated and largely preassembled clarification and filtration units, are commonly used in some sections of the United States by small water systems. An unpublished study has been completed on the cost-effectiveness of existing package water treatment plants. Visits were made to 36 package plants in Kentucky, West Virginia, and Tennessee. Of the 36 plants visited, data from 31 municipal and recreational plants were used for analysis.

The survey data demonstrate that package plants can meet traditional treatment goals with regard to bacteriological removal and turbidity. Plants that were not meeting the National Regulations had problems caused by lack of operator attention, e.g., not varying chemical dosage to meet changing raw water quality, or they were not running for lengths of time sufficient to achieve stable operation. Many automatic features, such as backwashing, were either not installed or not used in many cases because operators were reluctant to rely upon them or felt them to be untrustworthy.

Eight of the plants did not meet the Federal turbidity standard of 1 NTU. Table 8 lists the number of plants treating different ranges of raw water turbidity and whether or not they met the standard. One plant not meeting the 1 NTU standard used no chemical coagulants at all and is not included in the table. Of the plants not meeting the standard, only one operated more than 4 hr/day. The others not meeting the standard were oversized and thus were turned on and off throughout the day.

Fig. 7 shows the total unit treatment cost for package treatment plants. Fig. 7 clearly indicates that economies of scale in capacity and costs exist for package plants built and operated in a range less than or equal to 1 mgd. The typical construction cost for a 1-mgd plant is $1,124,000, while the cost for a 1-mgd

package plant is $479,000 (6). Based on construction cost alone, package plants appear to be a viable alternative for small systems.

A conclusion of this study is that package plants not only can produce water for small communities that will meet the requirements of the National Regulations, but also reduce the cost impact on small systems unable to achieve scale economies with conventional treatment. In addition, municipalities can, in many cases, purchase the proper capacity plant and do the necessary construction and connections for installation themselves.

Management Approaches.—Many examples exist of citizens in small communities banding together to solve their water supply problems. In some cases,

TABLE 8.—Turbidity Measurements

Turbidity of source, NTU (1)	Number of plants (2)	Finished Water	
		≤1 NTU (3)	>1 NTU (4)
≤5	14	11	3
6–15	8	8	0
16–50	6	2	4
51–100	0	0	0
<100	2	2	0

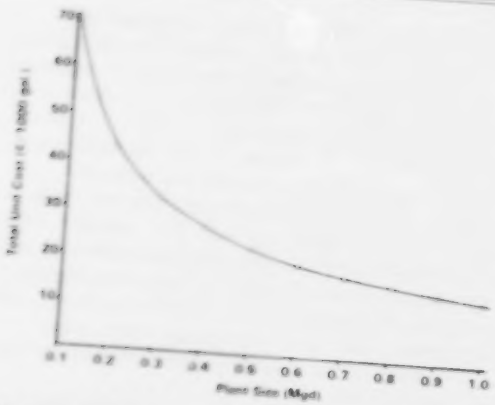

FIG. 7.—Total Unit Treatment Cost for Package Systems

volunteers may help lay pipelines or prepare a treatment plant site or actually manage the water system. Citizens working with a sympathetic consulting engineer can often acquire an effective water treatment system at a very reasonable price.

In addition to appropriate treatment technology, there are operational management techniques that might be applied to small systems. For example, the "circuit rider" concept has been proposed in which service would be provided to several plants who cannot individually afford a certified operator. The circuit rider

would provide attention to a number of plants and his salary would be shared among them.

As determined by the small systems studies mentioned earlier, there is a noticeable lack of consistent and reliable data upon which one can make realistic decisions. In order to correct this deficiency, research is being conducted into the development of cost accounting systems that can be utilized by small system managers to manage existing and new technology more efficiently. A survey of individual small water supplies found that records frequently were not kept on basic operating and capital expenditures. Often, when records were kept, they were retained as part of an overall municipal accounting system. Many times the municipal water supply managers kept no depreciation records and therefore based their charging schedule on operating and maintenance costs or on what an adjacent minicipality was charging for water. When capital was required, it was often "folded in" with general municipal bond requests.

Cost Accounting Systems.—One of the problems associated with small systems is that of obtaining reliable cost data. Many small system problems could be resolved if the proper data existed to help managers in planning for new technology. A major tool in achieving cost effective management is a standardized cost accounting system.

A small systems accounting tool is being developed. The system has been successfully implemented in Kenton County, Ky. and is designed to use the utility's existing chart of accounts and to determine costs on both a responsibility and product-costing basis. The following are inputs to the system: (1) Payroll; (2) work orders; (3) inventory / material; (4) accounts payable; (5) property records (capital equipment); and (6) billing information.

Using these inputs, costs may be assigned by major function within the utility: acquisition, treatment, delivery, support services, interest, and taxes. These costs are also allocated by service zone so that the manager can tell not only what his major cost centers are, but where they are occurring in the system.

Costs may be aggregated by major service function and area and engineering component as well as by organizational element. The utility manager can therefore determine his actual cost of service.

Once the cost accounting data base has been developed a financial reporting system can be interfaced to the accounting system. Financial reports can be generated that will allow the system manager to accurately assess the current and projected status of his system.

Summary and Conclusions

Over 90% of the Nation's supplies serve fewer than 10,000 people, but provide water to less than 25% of the total population served by community systems. Small systems in many ways are the victims of their size. They cannot benefit from economies of scale as large urban systems do because of their small number of connections. Small systems also seem to suffer from an inordinate number of finished water quality problems. All of these factors are compounded by the pressure for increasing water quality standards as exemplified by the Safe Drinking Water Act.

The incremental unit costs of technology may be high for small systems that are forced to install new treatment systems. Many efforts are under way to

find cost effective technological solutions for small systems problems. Surveys are being conducted to more clearly define the compliance deficiencies. Research is being conducted into technology for removal of specific contaminants, a problem frequently found in small systems. Package plants appear to be a cost-effective means of removing contaminants. Quasi point-of-use systems may have limited application and of course there are many possibilities for innovative solutions to small systems problems. Proper management of technology is another problem facing small systems. The "Circuit Rider" concept, cost accounting systems, and regionalization may all play a part in solving small system problems.

Acknowledgments

The writer would like to acknowledge the following individuals for their contribution to the preparation of this manuscript: Gary S. Logsdon, Thomas J. Sorg, Raymond H. Taylor, and Carl N. Shadix and his staff of the Drinking Water Research Division, MERL, EPA, Cincinnati; Dean Chausse, EPA Region VIII Office; Bernard Sarnoski and Koji Suto, EPA Regional III Office; W. Kyle Adams and James I. Gillean, ACT Systems, Winter Park, Florida; Robert C. Gumerman of Culp/Wesner/Culp, Consulting Engineers, Santa Ana, Calif.; and James Morand, University of Cincinnati.

Appendix.—References

1. Clark, R. M., "The Safe Drinking Water Act: Its Implications for Planning," *Municipal Water Systems: A Challenge for Urban Resource Management*, David Holz and Scott Sebastian, eds., Indiana University Press, Feb., 1978, pp. 117–137.
2. Clark, R. M., Gillean, J. I., and Adams, W. K., *The Cost of Water Supply and Water Utility Management*, Vol. I and II, Water Supply Research Division, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio, EPA-600/5-77-015a & b, Nov., 1977.
3. Community Water Supply Study: Analysis of National Survey Findings, U.S. Department of Health, Education, and Welfare, Public Health Service, Environmental Health Service, Bureau of Water Hygiene, Washington, D.C., July, 1970, pp. i–vi.
4. Craun, G. F., and McCabe, L. J., "Review of the Causes of Waterborne-Disease Outbreaks," *Journal of the American Water Works Association*, Vol. 65, No. 1, Jan., 1973, pp. 74–84.
5. Federal Register, Vol. 40, No. 248, Wednesday, December 24, 1975, "National Interim Primary Drinking Water Standards," pp. 59582–59583.
6. Gumerman, R. C., Culp, R. L., and Hansen, S. P., *Estimating Costs for Water Treatment As A Function of Size and Treatment Efficiency*, Drinking Water Research Division, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio, EPA-600/2-78-182, Aug., 1978.
7. Kneese, A. V., "Analysis of Environmental Pollution," *Economics of the Environment*, Robert Dorfman and Nancy S. Dorfman, eds., W. W. Norton & Co., New York, N.Y., 1972, pp. 21–44.
8. McDermott, J. H., Federal Drinking Water Standards—Past, Present, Future," *Journal of the Environmental Engineering Division*, ASCE, Vol. 99, No. EE4, Proc. Paper 9924, Aug., 1973, pp. 470–471.
9. National Interim Primary Drinking Water Regulations, U.S. Environmental Protection Agency, Office of Water Supply, EPA-570 19-76-003.
10. News of the Field-Update, *Journal of the American Water Works Association*, Vol. 70, No. 9, Sept., 1978.
11. Orlob, G. T., and Lindorf, M. R., "Cost of Water Treatment in California," *Journal of the American Water Works Association*, Vol. 50, Jan., 1958, pp. 45–55.

12. Sorg, T. J., "Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics," *Journal of the American Water Works Association*, Feb., 1978, pp. 105–112.
13. Sorg, T. J., and Logsdon, G. S., "Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics: Part 2," *Journal of the American Water Works Association*, July, 1978, pp. 379–393.

15181 SMALL WATER SYSTEMS: ROLE OF TECHNOLOGY

KEY WORDS: Costs; **Economic analysis;** Regional planning; **Regulations;** Systems analysis; Technology; **Water supply; Water treatment**

ABSTRACT: Over 90% of the nation's water supplies serve fewer than 10,000 people, less than 25% of the total population. Many of these small systems have problems. One of the major problems is their lack of operating revenues. They cannot benefit from economies of scale as do large urban systems because they are small in terms of the number of connections served. Recent epidemiological evidence has shown that the majority of the recent waterborne disease outbreaks occurred in small systems. There are, however, technological and management systems being developed that may aid small utilities in solving their problems at reasonable cost. These technological systems include package treatment plants and reverse osmosis plants. Management systems include cost accounting systems.

REFERENCE: Clark, Robert M., "Small Water Systems: Role of Technology," *Journal of the Environmental Engineering Division*, ASCE, Vol. 106, No. EE1, **Proc. Paper 15181**, February, 1980, pp. 19-35